Human Robotic Systems (HRS): Robotic Technologies for Asteroid Missions Element

Game Changing Development Program | Space Technology Mission Directorate (STMD)

ANTICIPATED BENEFITS

To NASA funded missions:

Very early development of asteroid technologies as a scaled R&D effort has the potential to greatly reduce development cost and schedule once mission requirements are set. The Asteroid Redirect Mission will benefit from the engineering data, analyses, designs, and results of prototyped hardware tests, which will inform asteroid mission planner decisions as mission concepts mature and are studied in more detail.

To NASA unfunded & planned missions:

Future missions to Mars or the moon, such as Mars 2020, could benefit from the engineering data, analyses, designs, and results of prototyped anchoring and sensing hardware tests from this study.

To other government agencies:

The technology developed for the network of anchoring end-effectors with sensors, which can be robotically implanted, could benefit the USGS with research for earthquake prediction.

To the commercial space industry:

The long-reach, tendon-activated manipulator research could lead to new capabilities that could be used on commercial space vehicles for astronaut positioning, payload deployment at the International Space Station, in-space assembly and construction, satellite servicing and repair, or spacecraft berthing operations.

To the nation:

The technology developed for the network of anchoring end-effectors with sensors could benefit oil companies in the search for new sources of oil, and could benefit Caltech and others researching earthquake behavior.

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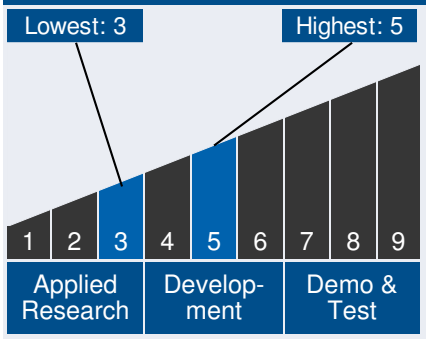
Technology Maturity



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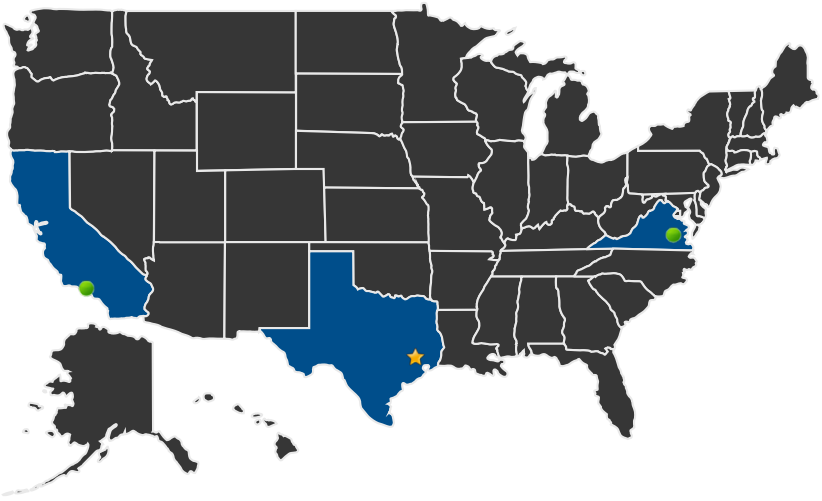
DETAILED DESCRIPTION

During 2014, the Robotic Technologies for Asteroid Missions activity has four tasks: Asteroid Retrieval Capture Mechanism Development and Testbed; Mission Operations Tools for Asteroid Capture and Retrieval; Prototype Anchoring End Effector for Asteroid with Sensors; and Develop Prototype Tendon-Actuated Manipulators to Enable In-Space Operations. The full descriptions for each task within this project element are listed under individual Technologies below:

U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
Johnson Space Center

Supporting Centers:

- Jet Propulsion Laboratory
- Langley Research Center

Other Organizations Performing Work:

- Caltech Community Seismic Network (CSN) (Pasadena, CA)

Realized Benefits

1 Success Story

Management Team

Program Executive:
- Lanetra Tate

Program Manager:
- Mary Wusk

Project Manager:
- William Bluethmann

Principal Investigator:
- Robert Ambrose

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LATEST SUCCESS STORY

2015-07-30 JPL Hedgehog

ELEMENT LIBRARY

Success Stories

- 2015-07-30 JPL Hedgehog
  - (http://techport.nasa.gov:80/file/16852)

Technology Areas

- Robotics and Autonomous Systems (TA 4)
- Sensing and Perception (TA 4.1)
- Manipulator State Estimation (TA 4.1.2.7)
- Manipulation Object State Estimation (TA 4.1.2.8)
- Space-Qualifiable Force and Torque Sensors (TA 4.1.5.1)
- Space-Qualifiable Tactile Sensors (TA 4.1.5.2)
- Free-Floating Robots (TA 4.2.4.1)
- Anchoring Robots (TA 4.2.4.3)
- Low-Altitude Above-Surface Navigation (TA 4.2.6.3)
- Small-Body/Microgravity Navigation (TA 4.2.6.5)
- Collaborative Mobility Algorithms (TA 4.2.7.1)
- Terrain Adhesion (TA 4.2.8.3)
- Sensing Terra-Mechanical Properties (TA 4.2.8.4)
- Actuators (TA 4.3.1.1)
- Motor Controllers (TA 4.3.1.3)
- Manipulator Concepts (TA 4.3.1.4)
- Dexterous Manipulator Arms (TA 4.3.2.1)
- Dexterous Manipulator End Effectors (TA 4.3.2.2)
- Mobile Manipulation (TA 4.3.4.1)
- Grappling (TA 4.3.7.1)
- Rendezvous Targeting (TA 4.6.2.1)

DETAILS FOR TECHNOLOGY 1

Technology Title

HRS - Asteroid Retrieval Capture Mechanism Development and Testbed

Technology Description

This technology is categorized as a hardware system for ground scientific research or analysis

NASA is currently studying an Asteroid Redirect and Utilization Mission using a robotic spacecraft to rendezvous, capture and steer a small asteroid to cislunar Space. In order to obtain a higher-fidelity understanding of mission/system dynamics, a proof of concept capture mechanism and testbed are required. During 2013, JPL internal funding was used to fabricate a basic testbed to study the two key issues that cannot be addressed purely through computer simulation: the possible binding of cinch-winch cords in the fabric of a capture bag and to realistically simulate the motion of the asteroid relative to the capture spacecraft by measuring actual forces (including fabric-snag forces) applied by the capture system to the asteroid. The prototype capture mechanism will be used to evaluate mission feasibility and research and development towards the flight capture mechanism design. A hardware testbed will be used to evaluate the capture mechanism design and to aid mission planning by iterating on a variety of mission scenarios. These simulated scenarios will help to reduce risk by studying the actions required to de-tumble, de-spin and safely transfer a small asteroid to a stable orbit in near-Earth space.

This task will extend an Asteroid Capture Testbed fabricated under JPL internal funding in 2013 and will simulate subscale asteroid capture physics with a prototype capture mechanism. The testbed will consist of a robotic arm instrumented with 6-axis force torque sensors that holds a rotating scaled asteroid, such that a full dynamic simulation of asteroid capture can be applied.

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
- Sensing and Perception (TA 4.1)
  - State Estimation (TA 4.1.2)
    - Manipulator State Estimation (TA 4.1.2.7)

Continued on following page.

Human Robotic Systems (HRS): Robotic Technologies for Asteroid Missions Element

A prototype capture mechanism will be designed, fabricated and tested under various mission scenarios with the simulator to insure forces on the spacecraft and capture bag are below design thresholds. Lessons-learned will inform a second-generation capture bag with improved (and more flight-realistic) fabric, inflatable structure, and cinch-winches.

Capabilities Provided

This task will provide NASA with the capability to test the design of prototype asteroid capture mechanisms and their performance in capturing a small rotating asteroid mockup on a physical testbed, which will include simulation of subscale asteroid capture physics with a prototype capture mechanism.

The test-bed's robotic arm will be capable of holding and rotating a scaled asteroid mockup, will be instrumented with 6-axis force torque sensors so that a full dynamic simulation of asteroid capture can be applied.

A prototype capture mechanism will be designed, fabricated and tested under various mission scenarios with the simulator to insure forces on the spacecraft and capture bag are below design thresholds. Lessons-learned will inform a second-generation capture bag with improved (and more flight-realistic) fabric, inflatable structure, and cinch-winches.

Potential Applications

The final results of this technology development will be delivered to Asteroid Redirect Mission (ARM) planners. These deliveries will provide engineering data that will inform decisions as mission concepts mature.

Very early development of asteroid technologies as an R&D scaled effort has the potential to greatly reduce development cost and schedule, once its mission requirements are set.

Lessons-learned from the capture bag tests will inform a second-generation capture bag with improved (and more

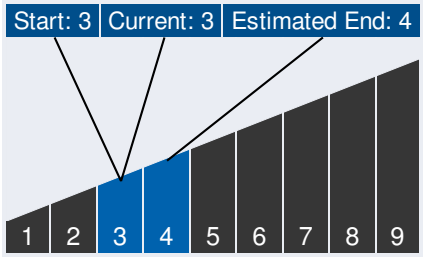
Technology Areas *(cont.)*

Additional Technology Areas:

- Robotics and Autonomous Systems (TA 4)
  - Sensing and Perception (TA 4.1)
    - State Estimation (TA 4.1.2)
      - Manipulation Object State Estimation (TA 4.1.2.8)
    - Force and Tactile Sensing (TA 4.1.5)
      - Space-Qualifiable Force and Torque Sensors (TA 4.1.5.1)
      - Space-Qualifiable Tactile Sensors (TA 4.1.5.2)
  - Mobility (TA 4.2)
    - Small-Body and Microgravity Mobility (TA 4.2.4)
      - Free-Floating Robots (TA 4.2.4.1)
      - Anchoring Robots (TA 4.2.4.3)
    - Robot Navigation (TA 4.2.6)
      - Low-Altitude Above-Surface Navigation (TA 4.2.6.3)
      - Small-Body/Microgravity Navigation (TA 4.2.6.5)
    - Collaborative Mobility (TA 4.2.7)
      - Collaborative Mobility Algorithms (TA 4.2.7.1)
    - Mobility Components (TA 4.2.8)
      - Terrain Adhesion (TA 4.2.8.3)

flight-realistic) fabric, inflatable structure, and cinch-winches.

Technology Maturity



Performance Metrics

Metric	Unit	Quantity
Asteroid max spin rate tolerated	RPM	1.0
Robotic arm max force	Newtons (N)	400

DETAILS FOR TECHNOLOGY 2

Technology Title

HRS - Develop Prototype Tendon-Actuated Manipulators to Enable In-Space Operations

Technology Areas

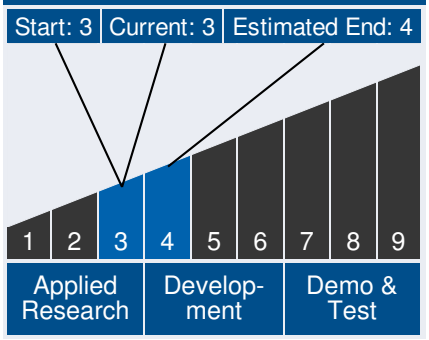
Secondary Technology Area: Robotics and Autonomous Systems (TA 4)

Technology Description

This technology is categorized as a hardware system for ground scientific research or analysis

Long-reach and compactly-stowable tendon actuated manipulators greatly improve the state-of-the-art in space robotics by significantly increasing manipulator reach and dexterity, while reducing mass and complexity, enabling new capabilities for asteroid redirect missions, as well as manipulation and astronaut positioning in cislunar space. During FY13, the design for a 300-meter long-reach manipulator was completed, and a prototype section of a compactly-stowable manipulator was fabricated, assembled and demonstrated mechanically. This technology is being evaluated as an alternative solution for asteroid capture.

Technology Maturity



Capabilities Provided

Efforts in 2014 will concentrate on development of a long-reach tendon-actuated manipulator concept, focusing on an embodiment that will enable asteroid capture and retrieval

operations. Results from the 2013 manipulator prototype section tests, along with requirements for an asteroid redirect mission, will be used to design a tendon-actuated manipulator. A limited set of key elements of the design will be fabricated with the goal of preparing to fabricate a complete manipulator (in FY15) that would be used to demonstrate new capabilities including: deployment from a stowed configuration; and robotic manipulation using a fully-antagonistic tendon control architecture with end-point control.

Potential Applications

The fully matured technology demonstrated in the 2-link TALISMAN could potentially provide new capabilities that could be used for asteroid redirect missions, manipulation, astronaut positioning, payload retrieval at ISS, in-space assembly and construction, satellite servicing and repair, and spacecraft berthing operations in a compactly-stowable form factor that would allow for easy launch of the mechanism.

Performance Metrics

Metric	Unit	Quantity
Structural Efficiency (tip force * length / mass)	N-m/kg	20

DETAILS FOR TECHNOLOGY 3

Technology Title

HRS - Mission Operations Tools for Asteroid Capture and Retrieval

Technology Description

This technology is categorized as complex electronics software for ground scientific research or analysis

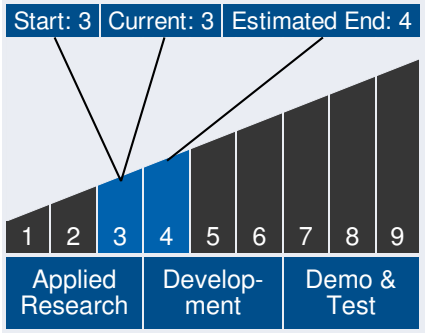
NASA's new Asteroid Redirect Mission would see a robotic spacecraft rendezvous, capture and steer a small asteroid to cislunar Space. Because of the complexity and novelty of the mission, success requires that first a testbed be developed so system behavior can be modeled and observed. This task will develop a testbed control system - to be used in conjunction with the Asteroid Retrieval Capture Mechanism Development

Technology Areas

Secondary Technology Area: Robotics and Autonomous Systems (TA 4)

task - that will provide a place to study data from a large number of possible mission execution scenarios, evaluate anomalies, and discover new operations principles that will reduce the risk associated with planning and executing an asteroid capture on the Asteroid Redirect Mission timeline.

Technology Maturity



Capabilities Provided

This task will develop and test a *telemetry and command* system for JPL's Asteroid Retrieval Testbed. The system will support multi-disciplinary investigation and provide the data capture, analysis and visualization tools to support collaborative assessment of system performance from large data sets, both captured and simulated. The team will demonstrate mission operations tools supporting tumbling asteroid capture and retrieval including: modeling spin and inertial state of the asteroid based on 3D sensing of the asteroid; estimation of angular momentum vector direction; and planning tools for estimating safe autonomous capture.

Potential Applications

The testbed control system will provide a *telemetry and command* system for the Asteroid Retrieval Testbed, and will be used in conjunction with the Asteroid Retrieval Capture Mechanism Development task. This will provide the capability to study data from a large number of possible mission execution scenarios, evaluate anomalies, and discover new operations principles that will reduce the risk associated with planning and executing an asteroid capture on the Asteroid Redirect Mission timeline.

DETAILS FOR TECHNOLOGY 4

Technology Title

HRS - Prototype Anchoring End Effector for Asteroid with Sensors

Technology Description

This technology is categorized as a hardware system for ground scientific research or analysis

Human exploration of Near Earth Asteroids (NEA) would be facilitated by emplacement of an array of anchors (preferably ahead of crew arrival) and knowledge of the internal structure of the NEA (especially knowledge that the configuration is not a gravitationally-unstable rubble-pile). This task develops prototypes for releasable/reusable anchors, for soft and hard surfaces, including a seismic source and sensors. The existing NASA ATHLETE robotic system will used to test emplacement of the sensor anchors and to drive the single-pulse thumper to test the seismic sensors. Under a separate technology task, the sensor anchors being developed under this task will be utilized by ATHLETE to anchor the robot to a steep slope to test the ability of a robot to climb a steep surface, utilizing a set of anchors which the robot can embed into the surface as it climbs, thereby giving it access to previously unreachable extreme terrain.

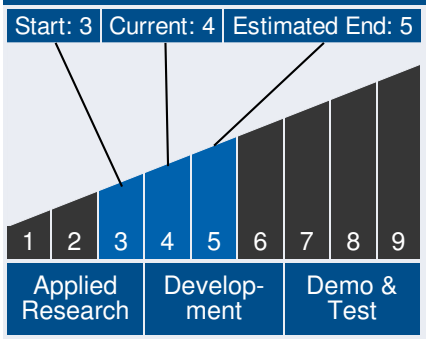
Capabilities Provided

Emplaceable/releasable/reusable anchors can serve human exploration by providing endpoints for safety tethers, allowing human explorers to maneuver over the surface of a Near Earth Asteroid (NEA) as with a “zip line”. Sensors embedded in the anchor could include acoustic/seismic emitters and receivers so that the array of anchors, perhaps emplaced by a fly-ahead robot that arrives several weeks ahead of the human crew, can perform internal tomography of the NEA. In prior work, a 1st prototype of an emplaceable/releasable/reusable anchor for soft

Technology Areas

Secondary Technology Area: Robotics and Autonomous Systems (TA 4)

Technology Maturity



regolith was demonstrated. During 2013, work on the task focused on prototyping and testing of a releasable/reusable anchor for both soft and hard surfaces, with a thumper and geophone. In 2014, work will be conducted to develop, build, and test a single-pulse thumper and a network of three seismic sensors. This work is being performed in partnership with the Caltech Community Seismic Network.

Potential Applications

This technology will provide valuable insight into the design and robotic emplacement of a system of anchors in both hard and soft asteroids, and will provide a means of sensing their internal structure, by including a sensor in the anchors, which will form a network once emplaced. In addition, this technology has several other potential off-world as well as terrestrial uses. A major oil and gas company has already expressed specific interest in emplacing seismic sensors in remote locations as part of the search for new oil and gas deposits. Earthquake research, sensing, and prediction require a huge number of seismic sensors over vast regions, which, in the future, could be better-placed by robots. For future planetary exploration, this anchor technology, used in conjunction with a robot that can emplace them, could also be used to enable robots to climb steep slopes in extreme terrain that is currently not accessible to planetary rovers.

Performance Metrics

Metric	Unit	Quantity
Anchor pull out force in microgravity	Newtons (N)	50